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No. 635

THE USE OF SLOTS FOR INCREASING THE LIFT OF AIRPLANE WINGS

By Fr. Haus

L'Aéronautique, June, 1931

THIS DOCUMENT ON LOAN FROM THE FILES OF

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LANGLEY MEMORIAL AERONAUTICAL LABORATORY
LANGLEY FIELD, HAMPTON, VIRGINIA

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August, 1931

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TECHNICAL MEMORANDUM NO. 635

THE USE OF SLOTS FOR INCREASING THE LIFT
OF AIRPLANE WINGS*

By Fr. Haus

The underlying principles of the most important devices for increasing the lift of airplane wings were indicated in a previous paper.** We will now state the problem and discuss in greater detail the results obtained with devices for preventing the separation of the boundary layer. In order to give an idea of the order of magnitude of the positive and negative pressures involved, we made a diagram of them (fig. 1), as measured at 15° angle of attack on the Göttingen profile 387. The pressure scale is graduated in terms of the dynamic pressure q , which enables the evaluation of the positive and negative pressures at all velocities. We have, in fact, $q = \frac{\rho V^2}{2}$.

I. Slots through the Wing

By establishing communication between the upper and lower surfaces of a wing, a pressure difference is obtained, the magnitude of which depends on the position of the slot. In a slot obtained by connecting the points A and A', the pressure difference would be $3q$. In a slot farther back (at BB', for example), the difference would be only $1.5q$.

The principle of the slotted wing is no mystery, and the name of this device well describes the method used. It produces a current whose kinetic energy is added to the failing energy of the boundary layer.

It is not our intention to discuss the origin of slotted wings. We shall refer, however, to Handley Page, who has attached his name to them and has improved them

*"L'utilisation pratique des procédés d'hypersustentation." L'Aéronautique, June, 1931, pp. 205-213.

**Fr. Haus, "Portances élevées et profils hypersustentateurs." L'Aéronautique, April, 1931, p. 125.

to the point of practical utility. The many researches made with slotted wings enable us to present the question in a systematic way and to examine methodically the properties of these surfaces. Our presentation will not always conform to the chronological order of the experiments. We will first consider the following questions:

1. Where should the slot be located?
2. What should be its cross-sectional shape?

a) Median slot.-- Since separation of the boundary layer on the upper side of a wing necessarily occurs at a point quite far back, it seems reasonable to produce the air jet quite far from the leading edge, near the point where the need of additional energy is apparent.

Let us consider, for example, an oblique slot (fig. 2) at about the middle of the chord. This has been found to increase the maximum lift. A test, made at the Rhode Saint-Genèse laboratory (Belgium) with a biconvex profile for which C_{m_0} was practically zero, yielded the following results. The slot x was of uniform width, and the wing had a chord of 200 mm (7.87 in.).

Width of slot x	Profile drag C_{xp}	Derivative dC_m/dC_z	Value of $C_{z_{max}}$	Angle of attack for $C_{z_{max}}$
Without slot	0.015	0.264	1.09	16°
2 mm	0.016	0.270	1.17	18°
5 "	0.018	0.290	1.29	19°
15 "	0.023	0.314	1.406	20°
25 "	0.030	0.340	1.450	21°

The test showed that $C_{z_{max}}$ increases with the width of the slot. The orifice of the slot increases the profile drag, but does not affect the value of C_{m_0} . It does affect, however, the value of dC_m/dC_z , that is, the inclination of the moment curve. The slot near the middle affects only the rear part of the wing. It increases the lift, corresponding to an increase of dC_m/dC_z .

The wings with slots of uniform width certainly do not constitute an advantageous solution. We refer espec-

ally to the preceding tests because of their systematic character, which shows all the peculiarities of the phenomenon.

There are certain advantages in using a nozzle-shaped slot, which produces a stronger flow. Figure 3 shows a profile tested at Göttingen, along with the corresponding polar. The C_z attains a maximum of 1.75, the other characteristics being:

Profile drag C_{xp} 0.07

Derivative dC_m/dC_z 0.30

b) Forward slot.— At the outset the question arises as to whether it is logical to use a central slot. It may be interesting to produce the air current near the point where it is to be utilized. The pressure difference is much less at the middle of the wing than near the leading edge. Would it not be better to utilize the pressure difference where it is the greatest? In this way the boundary layer is affected considerably forward of the point where it is necessary. What is the result? The laboratories can give us the answer. Figures 4 and 5 show the results obtained with the R.A.F. 31 wing and with a Göttingen wing.

Here also we have an increase in the maximum lift and an increase in the profile drag. The derivative dC_m/dC_z , on the contrary, diminishes instead of increasing, thus indicating that the c.p. tends to be farther forward than in the unmodified wing. This is not surprising, because the increase in velocity on the upper side of the wing, beginning at the leading edge, tends to increase the negative pressure in front. The test with the Göttingen wing shows an important discontinuity, a phenomenon which is quite often observed in the results of laboratory tests of slotted wings. The polar shows plainly that the regime, where the utilization of the slot becomes important, is the regime of high lift. It is there that C_{xp} reaches its minimum value.

It is known that slotted wings have long since left the domain of the laboratory. Of the two slot locations, central and forward, only the latter is now used. The reason is simple. The use of slots produce drags incompatible with high speeds. The use of a slotted wing appears to be really advantageous only when the slot can

be closed during normal flight and is opened only for flying at low speed, as in taking off or in landing.

The realization of this essential condition is almost impossible with the central slot. It would be necessary to place a spar in each part of the wing, which would prevent its displacement. It is quite different with the forward slot, where the slot is bounded by the wing itself and by an auxiliary surface which can be rendered movable without difficulty and which fits the wing exactly when the slot is closed.

c) Combination of slots with ailerons.— When slots are used the lift increase is due simply to the delay in taking off. The slots do not increase the value of C_z at small angles of attack. If it is desired to obtain great lifts, they must be sought at angles of attack of 24 to 26° , which abnormally incline the airplane and its fuselage to the flight path and require exceptionally high landing gears, if it is desired to land at these angles.

The properties of ailerons are already known. Their use increases the mean camber and angle of attack of the wing without increasing the inclination of the airplane to its flight path. By combining this property with that of the forward slots (fig. 6), large lifts are obtained without resort to large angles of attack.

It is necessary, of course, to insure the operation of the aileron in every instance. This result has been sought by the use of a second opening existing at the aileron hinge (fig. 7) and by activating, in some way, the motion of the boundary layer if, as a result of the change in direction produced by the operation of the aileron, this motion should cease. The rear slot, situated in front of the aileron, must remain open. An increase in drag will surely ensue. It seems, however, that the increase in the profile drag, produced by a slot, diminishes as the slot approaches the rear. The supplementary drag due to an aileron slot has been, in fact, reduced to $\Delta C_{xp} = 0.004$.

The R.A.F. 31 wing, provided with a front slot and an aileron gives, at a deflection of 20° , a lift of 1.9 corresponding to an angle of attack of 12° for the central part. The results obtained in France by Villiers and Bodiansky are also interesting. Figure 6 shows the characteristics of one of their profiles. The lift $C_z = 2$

is obtained by an aileron deflection of 20° at an angle of attack of $i = 11^\circ$ only.

These wings constitute the first practical application of supporting surfaces with more than one slot, whose properties have long since been determined in the laboratory. Moreover, the need of an aileron slot has not been demonstrated, good results having been obtained, in some cases by the simple combination of a forward slot and an aileron without slot at the hinge.

d) Action of slots on full-sized airplanes.— From flight tests on full-sized airplanes we know that the action of the slots is completely maintained at large Reynolds Numbers. Recent flight tests have made it possible, e.g., to determine the maximum lift of the well-known profile R.A.F. 34 provided with slots, but without ailerons. The tests were made on a biplane. The maximum lift of $C_z = 1.7$ was obtained at an angle of attack of 28° . As in the laboratory, the profiles provided with ailerons yielded greater lifts. The two victorious airplanes in the Guggenheim Contest both used this combination. The Curtiss "Tanager" and the Handley Page "Gugnunc" both showed exceptional speed ranges.

	Maximum speed in horizontal flight	Minimum speed Engine running	Engine stopped
Curtiss	179.6 km/h	49.2 km/h	59.7 km/h
Handley Page	180.5 "	53.7 "	63.8 "

The minimum speed of the Curtiss corresponds to a lift of 2.44, without taking into account, for the calculation of this coefficient, the area of the ailerons at the tips, always held at a small angle of attack. In the tunnel test, according to the official report, the model gave a maximum C_z of 2.36. The profile was the C 72.

The Handley Page wing, with the R.A.F. 28 profile, attained a lift of 2.12 with the engine stopped. These values were obtained, in both cases, with the slots open and the ailerons deflected.

The most characteristic property shown in the Guggenheim Contest and all the flight tests, is the improvement in the lateral stability and in the controllability of

these airplanes at large angles of attack. This improvement is the natural consequence of the use of slots. Those novel properties will be considered in detail farther on.

II. Wings with Pressure Slots

Before considering the properties of slotted wings from the viewpoint of stability, let us investigate wings with pressure slots. These differ only in the means used to produce the necessary jet of air. It will be interesting to compare, from the viewpoint of the resultant lift, the two applications of the same principle. For this purpose, let us first consider the results of three series of tests, as follows:

a) Tests at the Langley Memorial Aeronautical Laboratory.— The L.M.A.L. experimenters used a hollow wing with one or more slots in its upper surface. Our investigation was limited to a single combination where two slots were made at the points indicated on the profile. (Fig. 8.) These slots were disposed so as to guide the exit of the air, which was kept continually under pressure by a compressor. The inside pressure was carried successively to 4, 11 and 15 times the dynamic pressure. The coefficient of lift was found by integration of the normal pressures, in terms of the angle of attack. The results are shown in Figure 8. The drag was not measured in these experiments. Hence we cannot plot the polar nor determine the difference in drag ΔC_{xp} , positive or negative, due to the use of an air jet. We calculated, however, the output of air through the slots, the power corresponding to the compression of the air.

By making this power equal to an expression of the form $C_x S \frac{\rho V^3}{2g}$, of dimensions $ML^2 T^{-3}$, we can represent the power expended in compressing the air by a factor C_x' analogous to a drag coefficient. The C_x' , calculated and indicated in Figure 9, represent the theoretical work of compression. They are given in terms of the lift increment obtained at 12° angle of attack. If it were desired to use these figures to determine the requisite work, it would be necessary to increase them so as to make allowance for the efficiency of the compressors.

b) Katzmayr's tests at Vienna.— Katzmayr used a wing with three slots, one of them being on the lower side of the wing. (Fig. 11.) The curves in Figure 10 represent the polars in the case of a single slot in the forward part of the upper surface. Katzmayr's published results are given in terms of the ratio of the exit velocity u to the velocity of the air stream v . The two polars correspond to two different u/v ratios. The curves in Figure 11 represent the polars in the case of the three open slots.

The values of u/v are quite small. It is remarkable that a jet with a velocity of u , which is only a fraction of the air-stream velocity v , can yield such good results. Knowing u/v , it is possible to determine the internal pressure, which is a fraction of the dynamic pressure q . Katzmayr's measurements indicate the drags corresponding to the angles of attack at which the lifts are obtained. It is obvious that the circulation is considerably affected by the air jet and does not depend simply on the angle of attack. At a constant angle of attack the lift increases when the internal pressure and the exit velocity increase.

It is perhaps still more remarkable that the polars appear to shift while remaining approximately parallel. The polars do not follow regularly the induced parabola. The law of constant profile drag is poorly verified. On following the real polars in their course parallel to the axis of the ordinates, we find them, at certain angles of attack, becoming more favorable than the induced polar and intersecting the latter.

The emission of the air jets obviously exerts a favorable effect on the profile drag. The ΔC_{xp} are certainly negative. At constant internal pressure, the ΔC_{xp} are not independent of the angle of attack, but seem to vary with the lift. Here are phenomena, as yet but little understood, which we hope will soon be explained by new experiments. The appearance of a negative ΔC_{xp} constitutes a partial restoration of the energy expended in the compression.

c) Seewald's experiments at the D.V.L.— The experiments of Seewald in Berlin were characterized by the use of three strong internal pressures. The curves of Figure 12, showing the course of the lift in terms of the angle of attack, are very characteristic. C_z values of the or-

der of 3, attaining even 3.3, were obtained with an internal pressure of 4 atmospheres.

d) Comparison of the results.— The system of air jets yielded lift increments of the same order of magnitude as those obtained by slots passing entirely through the wing.

Katzmayr's experiments were made with very low internal pressures, equal to only a fraction of q . They enabled the attainment of $C_z = 2.2$. The American experiments (with internal pressures up to 15 q) yielded practically the same result. Seewald's experiments were performed at much higher pressures, of the order of 200 to 500 q . The C_z increment was greater, the $C_{z_{max}}$ attaining 3.3. All these tests show that appreciable effects can be produced with quite low pressures.

In none of these series of tests were all the important characteristics determined simultaneously. In the American tests the difference in the drag ΔC_{xp} was not measured, but the energy required for the compression was found. In the Austrian experiments the drag was measured, which enabled the determination of ΔC_{xp} . This was found to be negative. The amount of the compression work was not determined in these tests. Seewald's measurements involved only the lift.

For the lack of complete data, it is difficult to judge the value of wings with pressure slots. No measurement of C_m was made, although this coefficient would be the most useful.

The comparison of wings having through slots with wings having pressure slots is to the advantage of the former. For attaining C_z of the order of 2, wings with through slots yield the desired result in a simpler way without complicated mechanical devices. It is only by verifying the somewhat paradoxical results of Katzmayr at very low pressures that the practical application of pressure slots could be predicted.

III. Wings with Suction Slots

Wings provided with suction slots on the upper side have been tested in several laboratories. There is no need of explaining their principle. We will only indicate the principal results.

a) Experiments at the Langley Memorial Aeronautical Laboratory.— The wing used in the American experiments was provided, on top, with a series of suction orifices. Their edges were slightly rounded, so as to facilitate the intake of air. Rather small negative pressures were employed. The curves in Figure 13 indicate the lifts obtained, for different negative pressures, with a wing having three slots. The curve in Figure 14 indicates, in terms of the lift increment at 15° angle of attack, the drag C_x' corresponding to the theoretical work of suction.

b) Schrenk's experiments at Göttingen.— Oskar Schrenk's experiments were performed on very thick wings, using different dispositions of the suction slots. We will only give the results of one of the most characteristic tests. The negative pressures were of the same order of magnitude as in the American tests. Since the drag measurements were made, it is possible to represent the results by the customary polars. (Fig. 15.) It is manifest that the angle of attack here retains all of its importance. The suction does not increase the circulation. The work of suction having been determined, it was possible to represent the polars (fig. 16) in terms of a total drag $C_x + C_x'$, which makes it possible to determine the power required for utilizing such a disposition.

These laboratory tests, like those on wings with pressure slots, led to no practical results. The tests indicate, moreover, that the properties of wings, provided with these slots, are bad when the desired positive or negative pressure is not produced internally, i.e., when the lift-increasing device is not in operation.

In order not to confuse the figures, we have omitted the curves for internal positive or negative pressures of zero. We will simply remark that they are much worse than those of a plain wing without slots.

IV. Effect of Lift-Increasing Devices on the Stability

We now broach a new aspect of the problem, an aspect which is, perhaps, the most important of all. Airplanes have, inherently, one fundamental defect. This defect consists in dynamic lateral instability, whenever an airplane has an angle of attack above the angle of maximum lift. This fact is easy to understand. Let us consider the reactions of an airplane when disturbed laterally.

When a wing is tipping downward, its angle of attack is increased by the relative velocities, while the angle of attack of a rising wing is diminished.

If the airplane is flying at an angle below that of maximum C_z , called the critical angle, the descending wing (whose angle of attack is being increased by this movement) is subjected to a greater lifting force, while the ascending wing is subjected to a smaller lift. This difference tends to lessen the disturbance.

If the airplane is flying above the angle of maximum lift, the lift of the descending wing decreases, due to the increasing angle of attack, while the lift of the ascending wing increases, and the disturbance tends to increase instead of diminish.

In curving flight the velocity of the outer wing is greater than that of the inner wing. Since the reactions are always proportional to the square of the velocity, the lifting force exerted on the outer wing (i.e., the ascending wing) increases and the rolling motion is increased.

It is easy to recognize in these reactions the tendency to start a spin. An accidental spin, in short, may be considered as a secondary consequence of the separation of the boundary layer from the wings. For ordinary wings the critical angle of 15 to 18° is not far from the angles at which the airplanes are generally flown, as is demonstrated by the frequency of accidents due to accidental spins.

Lift-increasing devices which increase the critical angle and defer the separation of the boundary layer to higher angles, thus increasing the angle-of-attack range, necessarily increase the safety.

It is hardly possible, in a single article, to make a complete study of the relations existing between the use of slots and the improvement of lateral stability. We can only explain the principle.

Let us note, however, that the forward slots improve the functioning of the ailerons. It is known that conventional ailerons, when deflected downward, increase both the lift and the drag. Lowering, for example, the right aileron, increases the drag on that side and initiates a turn to the right. This tendency to turn is a secondary effect, which must be offset by the rudder.

As the angle of attack of the wing increases, the lift increment due to the aileron deflection diminishes, while the drag due to this movement increases. Deflecting the aileron has the same effect as increasing the angle of attack and produces, if the angle is large, the phenomena characteristic of exceeding the critical angle at large angles of attack on a conventional wing, the rolling moment due to the ailerons diminishes, and the secondary moment of yaw or gyration increases and may predominate. This moment is harmful because the turning it produces tends to increase the rolling which the operation of the ailerons is designed to combat. Thus it is obvious why the operation of the ailerons on an airplane flying at a large angle of attack starts a spin so quickly.

With forward slots the case is not the same, the above phenomena are produced much less readily and the controls retain their efficacy over a much wider range.

V. Automatic Slots

Experience has shown that the slots are of incontestable value in the event of stalling or, more generally, of an abnormal increase in the angle of attack.

An airplane equipped with slotted wings generally flies, however, with the slots closed. If an unexpected stall (more accurately an increase in the angle of attack) then occurs, the pilot does not have time to open the slot and is deprived of its aid just when he needs it most. This is a serious objection to the use of slots, and it must be recognized that, in fact, there are hardly any airplanes in use with controlled slots.

There has been discovered, however, one circumstance of capital importance in the development and use of slotted wings. According to pressure-distribution diagrams, the portion of the top of the wing near the leading edge is under positive pressure at small angles of attack, while it is under negative pressure at large angles. This fact was utilized by Handley Page to make the operation of the slots automatic.

At small angles of attack the auxiliary wing is pressed against the main wing by the positive pressure. At large angles of attack, near the critical angle, the positive pressure gives place to a negative pressure and the auxiliary wing advances. The slots, therefore, open automatically just when they are needed. Due to this property it was found possible, after perfecting the supporting system of the auxiliary wing, to dispense with the hand control of this part. Thus originated the automatic slot, whose qualities and properties have been described in numerous pamphlets or circulars of a more or less commercial nature.

As to what may reasonably be expected of automatic slots, it is of interest to note that their inventor, Handley Page, advocates their use over only a part of the span, namely, near the wing tips opposite the ailerons. Their purpose, therefore, is to increase the critical angle of attack of a portion of the wing. No general increase in the lift is sought, but only a local increase at the wing tips.

In this case the landing speed is not greatly reduced, but it may be established, without inconvenience, at the angle of attack corresponding to the maximum lift of the whole, because, at this angle, the wing tips are still below the critical angle.

The influence of the tips is predominant as regards the damping of the rolling motion. An airplane equipped with wing-tip slots can be leveled off without fear of a spin, and the ailerons, being located on the portion of the wing which has not exceeded the critical angle, will retain their efficacy.

The objects served by slotted wings are gradually becoming clearer. A reduction in the maximum speed is sought only in certain special applications, such as Gug-

genheim Contest airplanes and those designed to alight on ships. The trend of most of the present slotted-wing airplanes is to use slots only at the wing tips and to seek especially their stabilizing effect. This disposition affords a welcome increase in lift, but the controlling idea is to enable the complete utilization of the existing lift, by making flight practicable and safe up to the highest point of the polar.

VI. Conjugation of the Slots with the Ailerons

The maximum lateral control at large angles of attack can be obtained on an airplane provided with slots by conjugating them with the ailerons. In order to produce differences of lift between the ends of a wing at a large angle of attack, it is, in fact, obvious that one must not be limited to operating the aileron alone, but must also be able to operate the slot simultaneously. Various systems of conjugation, closing the slot on the end where the aileron is deflected upward, have been tried and found efficacious. The secondary effects of these controls can be favorable instead of unfavorable, because the elimination of the device for increasing the lift in front of the wing, which it is desired to lower, increases the drag and places this end near the center of the turn instead of at the outer side as is the case when the aileron of a conventional wing is elevated.

These controls often proved very difficult to operate and required great exertion on the part of the pilot. The Handley Page Company then invented the "interceptors." These are small surfaces which, without touching the auxiliary wing, close the slot on the tip of the wing to be lowered. The effect of this slot is thus eliminated with much less effort than would otherwise be required to close the slot.

VII. Influence of the Longitudinal Stability

By using slots, the characteristics of an airplane can be improved at large angles of attack, and the angle of maximum lift can be rendered practically utilizable, which is not the case on ordinary airplanes. Modifications in the usual conception of an airplane, as regards longitudinal controllability, must logically accompany the use of slots. In fact, an ordinary airplane should not, theo-

retically speaking, be capable of flying at a dangerous angle of attack. This desideratum can be realized by correctly combining the efficacy of the control with the static stability.

The airplanes are rare which satisfy this condition. There is a well-known commercial monoplane which cannot stall nor go into a spin. Those properties have long seemed surprising, considering that this airplane is of a good aerodynamic design, although altogether orthodox. The mystery vanishes when it is found that the airplane has relatively weak controls, and that, with normal balancing, it is hardly possible to attain its maximum lift by deflecting the elevator to its fullest extent. Such a solution, which is justified on an airplane without slots, would not be justifiable on an airplane provided with slots, because it would prevent the airplane from benefiting fully by the slots. Airplanes with slots must therefore, as regards longitudinal controllability, differ from orthodox airplanes in their characteristics.

This viewpoint did not escape Mr. Potez, who constructed a touring airplane with fixed slots. Potez and Jarry demonstrated that the use of slots produced modifications in C_m and C_z , which lessen the longitudinal static stability and which, for the same deflection of the elevator, give the airplane a greater angle of attack.

It seems therefore that the modifications in the longitudinal stability of an airplane, as introduced by the use of slots, are in the desired direction.

VIII. Wings with Pilot Planes

The possible combinations are not limited to those we have described. Experiments have been tried with a particular disposition of the forward surfaces, which enables the realization of a wing passing automatically and progressively from normal regimes to those of greater lift, by simply varying the angle of attack. This result is obtained without the aid of the pilot, as with the controlled slot, and without sudden shifting of an auxiliary wing, as with an automatic slot. It is due to the use of a surface free to oscillate about an axis. Such a surface is called a "pilot plane" in England. (Fig. 17.)

In front of the main wing a small airfoil or pilot plane swings freely about an axis near its leading edge. Under the action of the air, this pilot plane takes the position of least resistance, or nearly so. The upward rotation is limited so as to stop the pilot plane in a predetermined position. It is perfectly free, however, to move downward. At small angles of attack, the pilot plane floats in the air current and does not affect the action of the air on the main wing. At high angles of attack, the pilot plane rotates so as to raise its trailing edge, forms a slot in front of the main wing and acts like the auxiliary wing in front of an ordinary slotted wing. The experiments of Bodiansky and Villiers showed that interesting polars (fig. 17) can be obtained by combinations of this kind.

Flight tests, especially the results of the Guggenheim Contest, have confirmed many of the conclusions reached in the laboratory. We hope that our summary of the principal results obtained with the various lift-increasing devices, will not be altogether useless, because we believe that the facts established in the laboratory will always constitute logical bases for full-sized constructions.

Translation by Dwight H. Miner,
National Advisory Committee
for Aeronautics.

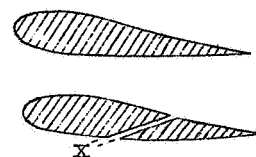
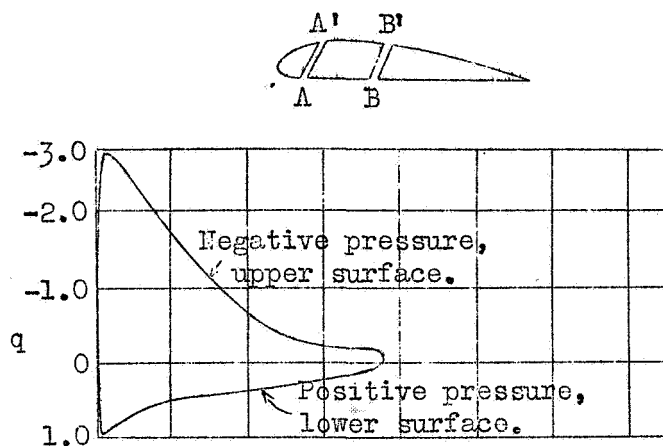


Fig.2 Biconvex profile with slot x of variable width.

Fig.1 Distribution of positive and negative pressures. Göttingen profile 337 at 15° angle of attack. (Negative pressure, upper surface; positive pressure, lower surface).

A, Induced parabola, aspect ratio 6.

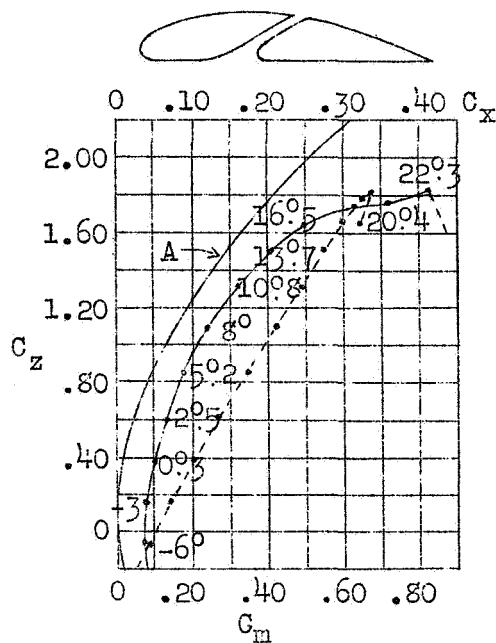


Fig.3 Polar of wing profile with central slot, tested at Göttingen. (Induced parabola, aspect ratio 6.) $C_{z \text{ max.}} = 1.75$; $C_{x \text{ p}} = 0.07$.

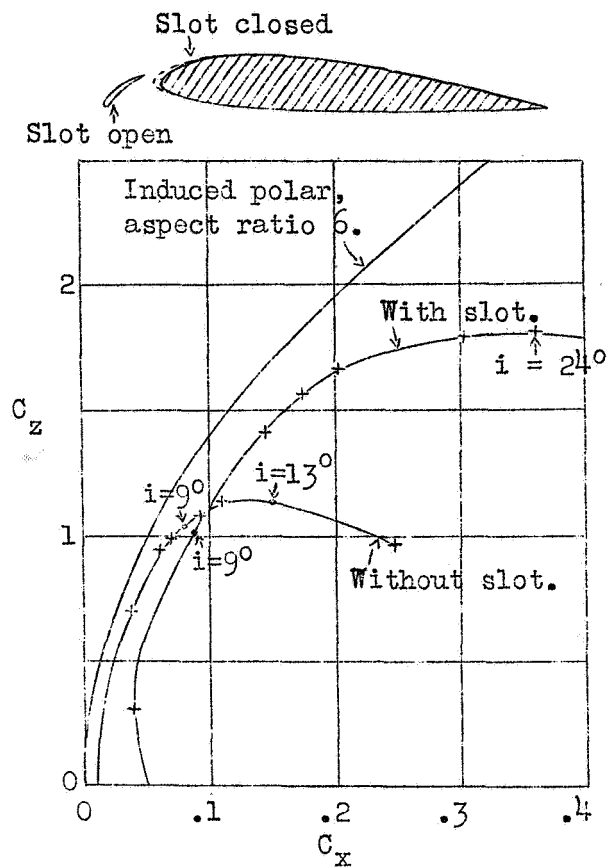


Fig. 4 Polars of R.A.F. 31 with and without slot.
(Induced polar, aspect ratio 6.)

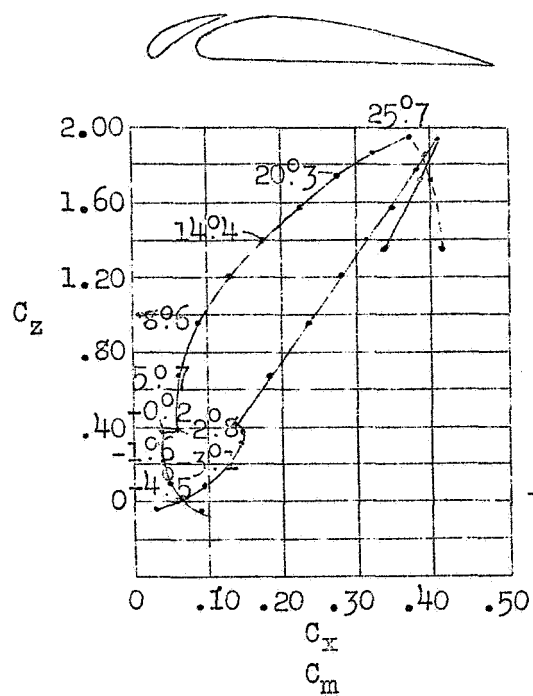


Fig. 5 Polar of wing profile with front slot, tested at Göttingen. Note discontinuity between -0.2 and 2.8° .

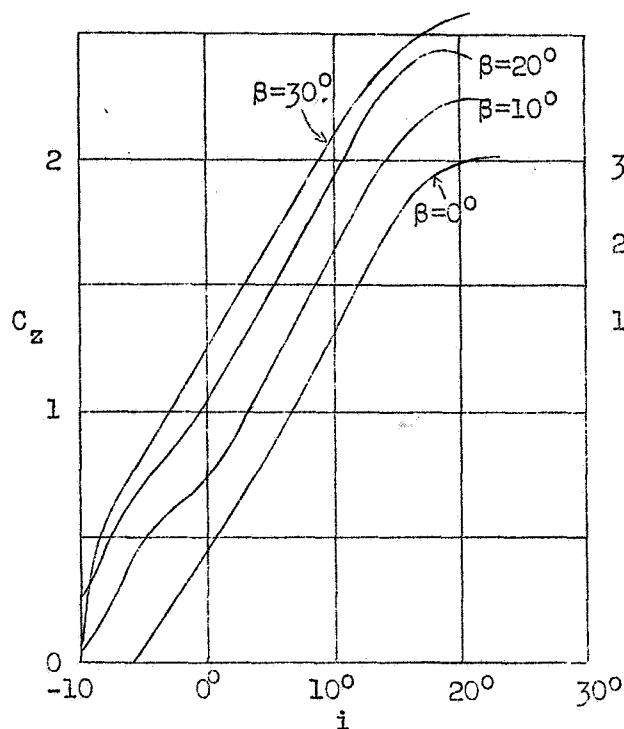


Fig. 6 Lift of Villiers profile A'6 with slot and aileron.

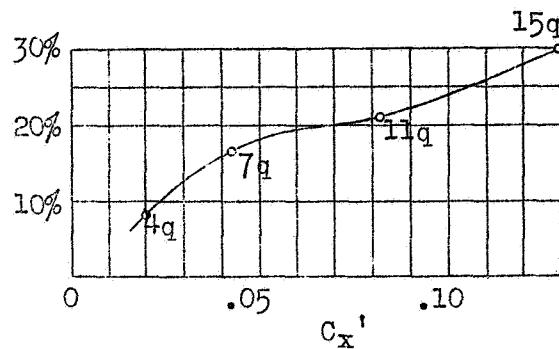


Fig. 9 Relative lift increment in terms of power expended. C_x' is given in terms of the lift increment at $i=15^\circ$.

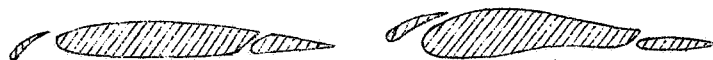


Fig. 7 Profiles with slots in front and at aileron hinge. Left, R.A.F. 31; right, Villiers A'6.

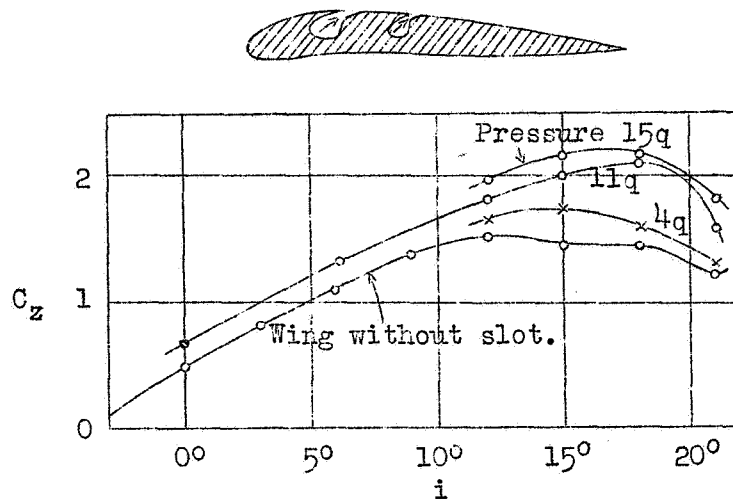


Fig. 8 Lift of wing with pressure slot. Tests at Langley Memorial Laboratory.

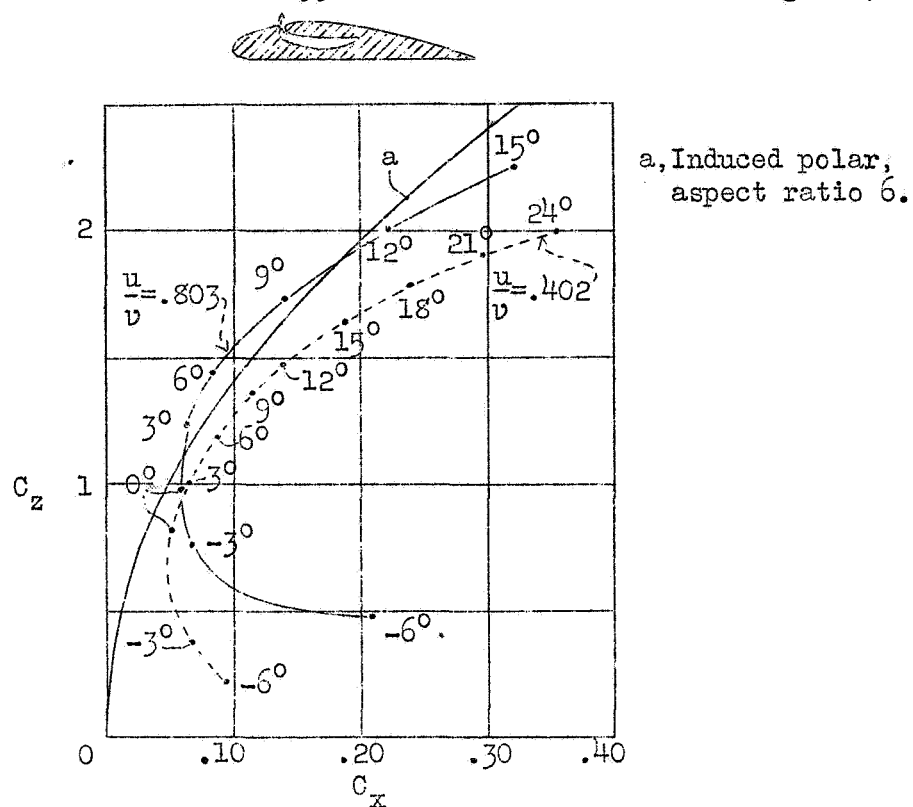
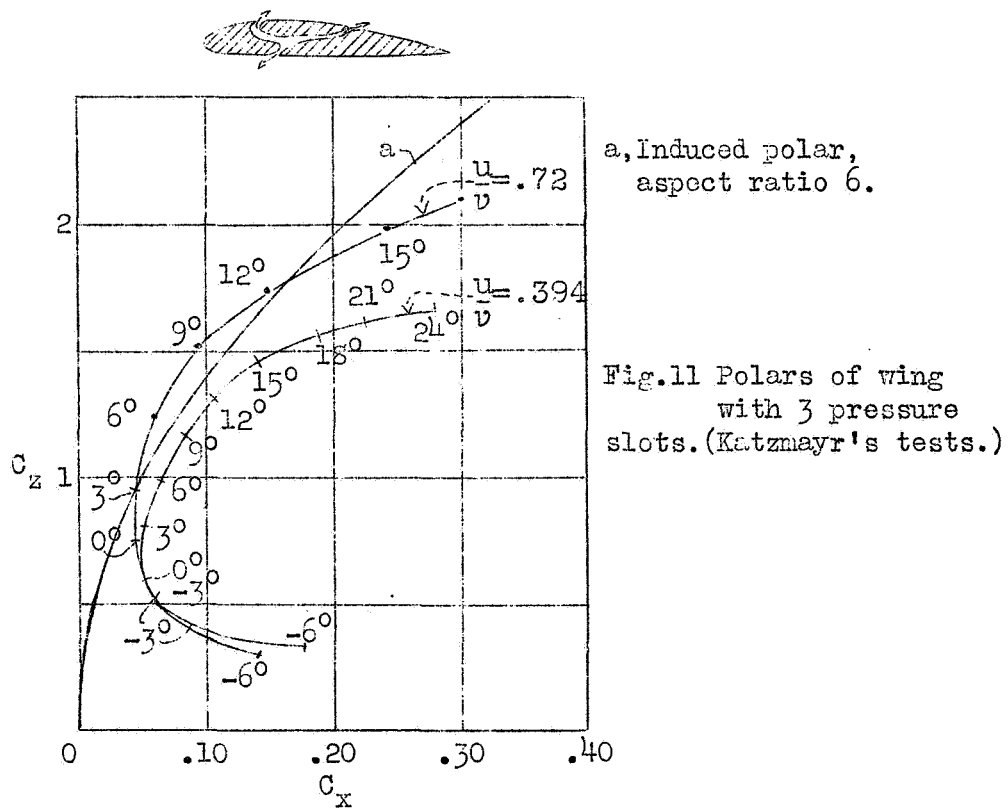


Fig.10 Polars of wing with single pressure slot, Katzmayr's tests.



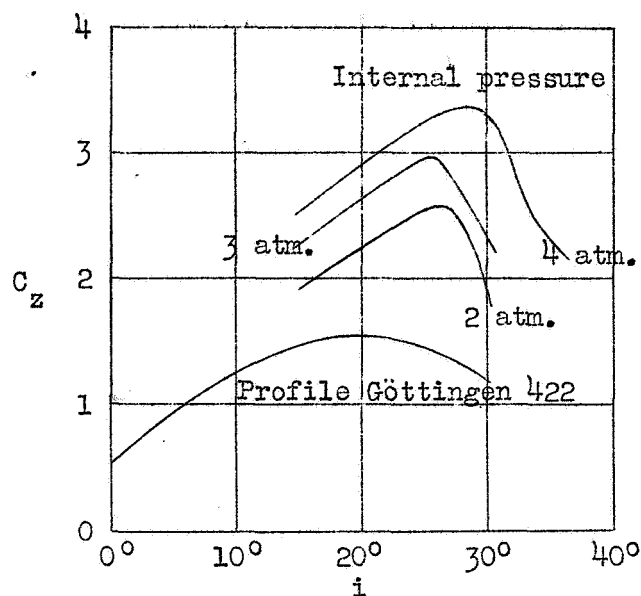


Fig.12 Lifts obtained by Seewald with very high internal pressures.

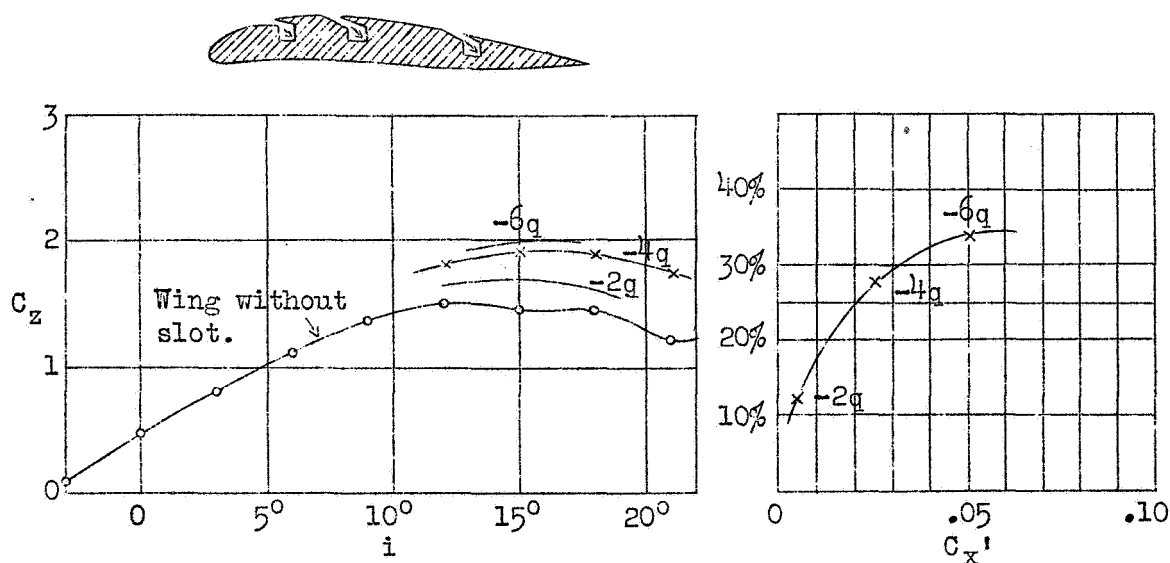


Fig.13 Lift of wing with suction slots, for 3 values of the internal negative pressure.

Fig.14 Relative lift increment in terms of expended power. (Angle of attack 15°)

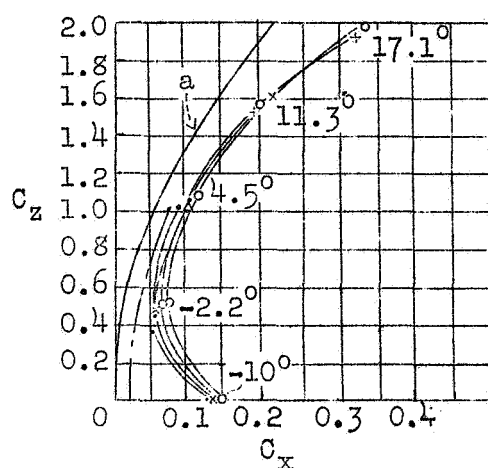


Fig.15 Polars of suction wing
for 5 values of the
internal pressure.

Curve b, internal press. = $-1.5q$
 " c, " " = $-2.2q$
 " d, " " = $-2.8q$
 " e, " " = $-3.5q$
 " f, " " = $-5.3q$

a, Induced polar, aspect ratio 6.

a, Induced parabola, aspect ratio 6.

× Internal pressure = $-1.5q$
 + " " = $-2.2q$
 Δ " " = $-2.8q$
 • " " = $-3.5q$
 O " " = $-5.3q$

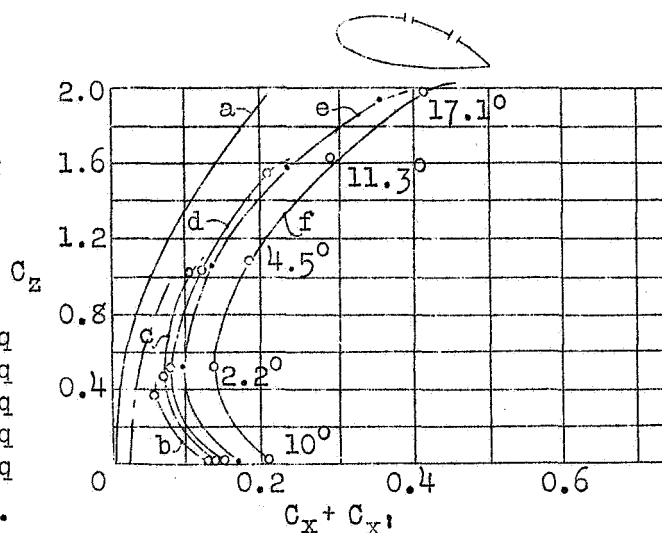
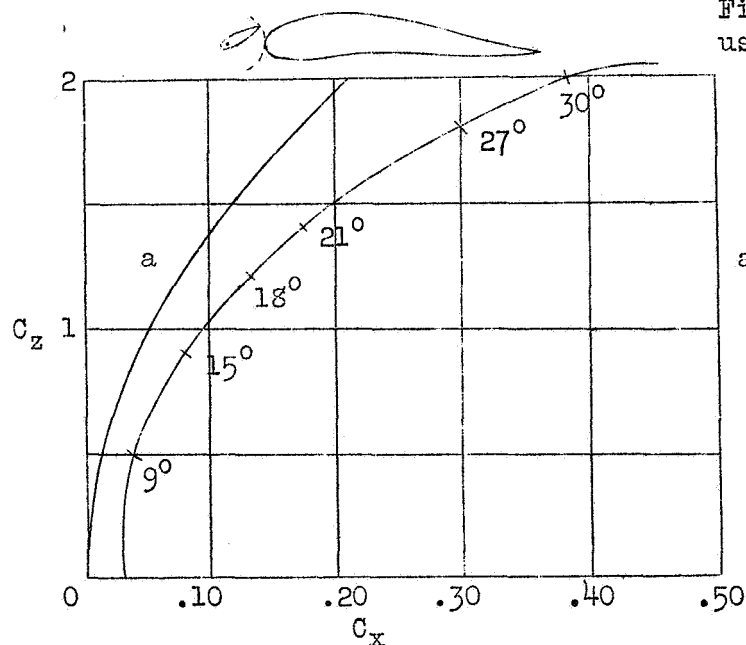


Fig.16 Polars of same wing as in
Fig.15, allowing for power
used in suction.



a, Induced parabola, aspect
ratio 6.

Fig.17 Polar of wing with "pilot plane".